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(71) Applicant
The Plessey Company plc

(Incorporated in the United Kingdom)

Vicarage Lane, Ilford, Essex, IG1 4AQ,
United Kingdom

(72) Inventors
David John Pedder
Michael John Wale

(74) Agent and/or Address for Service
F Lupton
The Plessey Company plc, Intellectual Property Department, Vicarage Lane, Ilford, Essex, IG1 4AQ, United Kingdom

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U1S S1914

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(58) Field of search
UK CL (Edition J) B6J JME JMF JMX, G2X XB20A XB3B, H1K KLEC KLEX KMWX KQAG
INT CL⁴ G03C, G03F, H01L

# (54) A method of processing substrates used for mounting and aligning optical elements and components

(57) A method of processing a substrate, comprising:

a) providing on an anisotropically etchable substrate, e.g. silicon (2), a layer of $S_iO_2$ (30), a metal layer (32) and a photoresist layer (34),

b) forming by patternwise exposure and etching a desired pattern in the metal layer in a first area and a second area, the first and second areas being accurately located relative to one another;

c) forming and exposing a photoresist masking layer (44) over the second area and etching the $S_iO_2$ layer in the first area and developing the photoresist in the second area, anisotropically etching a V-shaped groove in the first area, and etching $S_iO_2$ in the second area to leave overhung side walls (50), depositing a meltable metal (60) in first and a second areas so that solder can be depositied thereon,

d) and etching away the remainder of the $S_iO_2$ and metal layers to produce a substrate which can accept optical fibres in the V-grooves and optical elements on the solder pads in the second area, the fibres and elements being accurately aligned.

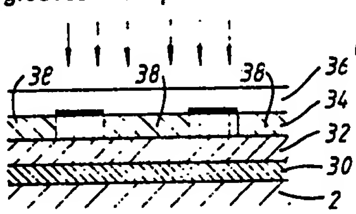


Fig. 2.

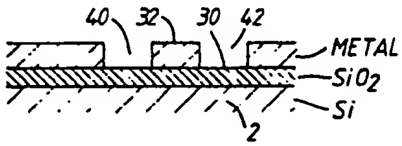


Fig. 3.

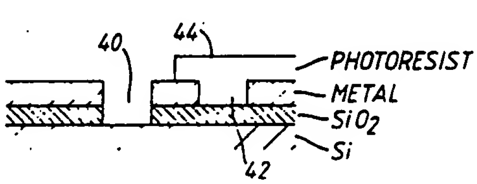


Fig. 4.

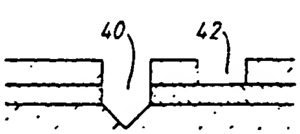


Fig. 5.

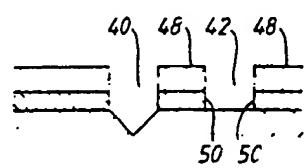


Fig. 6.

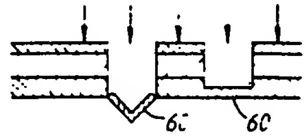


Fig. 7.

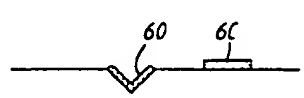


Fig. 8.

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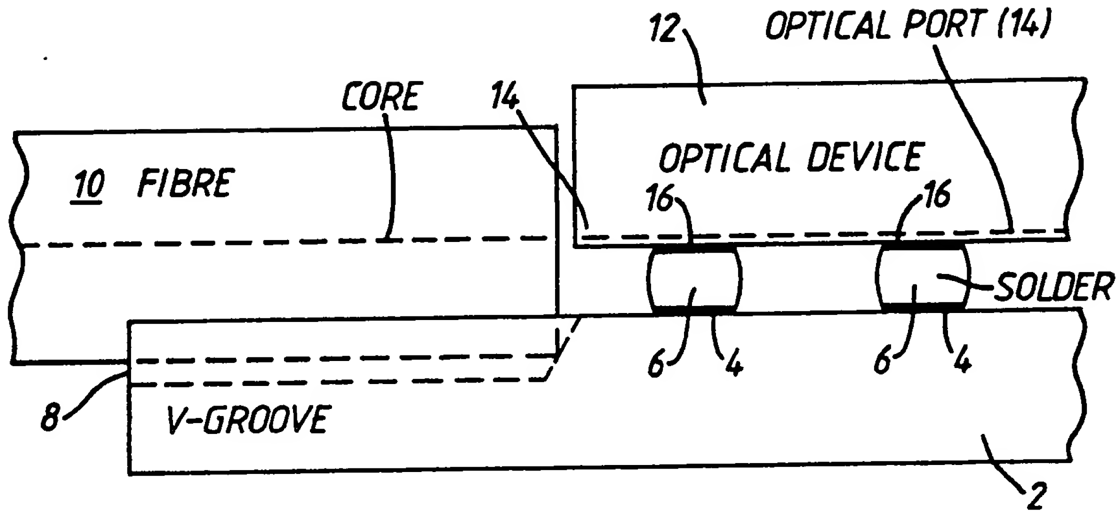
12
OPTICAL PORT (14)
CORE
14
OPTICAL DEVICE
10 FIBRE
16
16
SOLDER
6
4
6
4
8
V-GROOVE
2

Fig. 1.

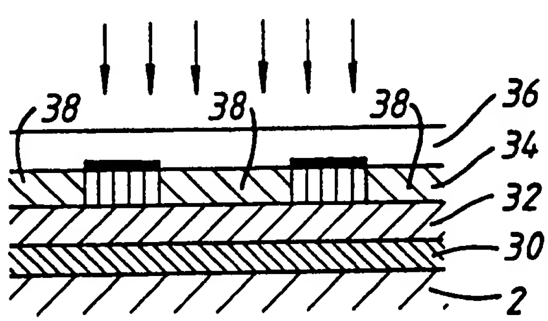
38
38
38
36
34
32
30
2

Fig. 2.

2/2

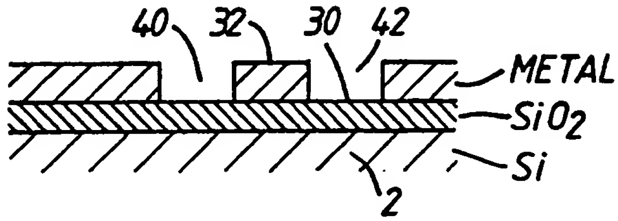


Fig. 3.

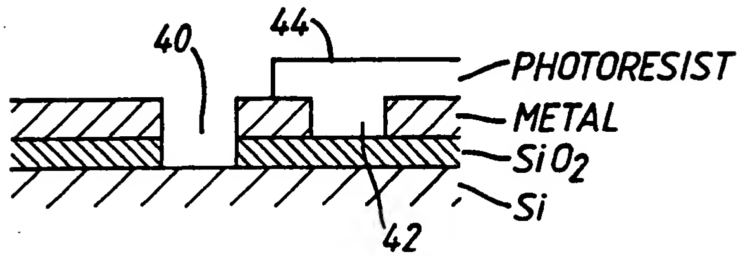


Fig. 4.

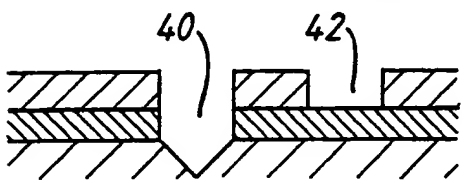


Fig. 5.

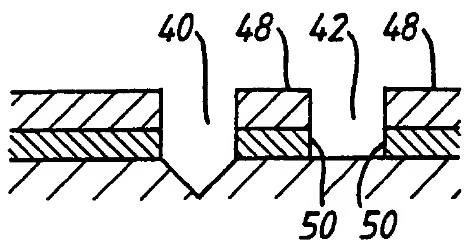


Fig. 6.

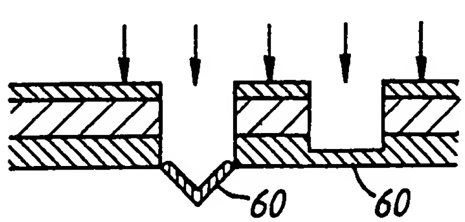


Fig. 7.

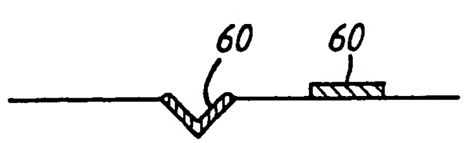


Fig. 8.

# A METHOD OF PROCESSING SUBSTRATES FOR MOUNTING OPTICAL ELEMENTS AND COMPONENTS

The present invention relates to a method of processing substrates for mounting optical elements and components.

In our copending application 8719557 (Ref. F20389) there is described a method of optically coupling an array of optical elements (principally optical fibres) with optical components (laser diodes, photodiodes, waveguides) by a method comprising:

a) providing a substrate having formed thereon locating means for receiving said optical elements;

b) forming on the substrate an array of solder pads each of predetermined area surrounded by areas which are solder-repellent;

c) forming on the or each block an array of solder pads each of predetermined area surrounded by areas which are solder repellent, the solder pads on the or each block being in one-to-one correspondence with the solder pads on the substrate;

d) depositing on some or all of the solder pads controlled amounts of solder; and,

e) locating the optical elements in the locating means and positioning and securing the or each block on the substrate with the respective arrays of solder pads in registration and the controlled amounts of solder forming solder drops of predetermined dimensions which serve to secure the blocks and align the blocks in the plane of the substrate and in a height dimension normal to the plane of the substrate.

The aforesaid method is an adaptation of the well known controlled collapse reflow chip bonding (CCRB) techniques ("flip-chip solder bump bonding") to the problems of optical alignment.

A problem which arises in the execution of the above method is the accurate positioning of said locating means relative to said solder pads on the substrate.

Thus it is an object of the present invention to provide a method of forming on a substrate surface accurately positioned solder pads and locating means for optical elements.

The present invention provides a method of processing a substrate comprising:-

a) providing a substrate of a material which permits anisotropic etching;

b) forming a layer of a barrier material on the substrate surface and forming a desired pattern in the barrier material by selective removal of the barrier material to provide one or more first areas and one or more second areas, the first and second areas being accurately positioned relative to one another;

c) forming a mask over the or each second area and producing in one or more etching steps, an anisotropically etched V-shaped groove in the or each first area, and predetermined surface portions in the or each second area; and,

d) etching away the remainder of the barrier material.

As preferred, the predetermined surface portion in each second area comprises a clean substrate surface area onto which solder pad material may be deposited to form a solder pad. Alternatively some

other surface may be formed as for example the surface of a Fresnel lens etched into the substrate surface.

Thus in accordance with the invention, there is provided a method of processing a substrate which can accurately locate V-shaped grooves for accepting the ends of optical fibres relative to solder pads for receiving and locating an optical component. The method is simple to execute since it depends for its accuracy on a single step of forming a desired pattern in a layer of barrier material formed on the substrate surface. Thus multiple masking techniques are avoided. Whilst any type of pattern forming process may be used, for example electron beam writing, it is preferred to use an optical lithographic technique. The barrier material may be a layer of $SiO_2$ grown on the substrate surface by a suitable oxidation technique. Such a layer, which is a relatively etch resistant material, permits the application of etchant to produce V-shaped grooves along the <100> plane of the silicon substrate by the well-known anisotropic etching technique. After the V-shaped grooves are etched in silicon, the mask material over the second set of areas is etched away preferably to leave a clean substrate surface area on each second area so that a layer of metal may subsequently be deposited on the second areas to define solder pads. At the same time such metal may be deposited in the V-shaped grooves to permit soldering of the optical fibres within the grooves.

During the etching of the second areas, the etchant will attack the barrier material surrounding the second areas after it has removed the mask material and this will result in "over-hung" regions so that the second areas are effectively widened. Thus when

the metal is subsequently deposited on the second areas there will be a gap between the edge of the metal and the barrier material. This lends itself to the subsequent etching away of the remainder of the barrier since when the etchant is applied it can penetrate between the metal and the barrier material in order to lift off the barrier material simply and cleanly.

Whilst the method according the the invention is of particular use in the location of fibre elements relative to optical components such as integrated optical circuits and laser diodes as described in our copending application 8719557 <F20389>, it may nevertheless be used in other processes and applications, for example the second areas may provide a Fresnel prism etched into the substrate surface. Alternatively any other type of component be it optical or electrical may be located in accordance with the invention if it has to be located very accurately relative to a further set of areas.

While the V-shaped grooves are intended specifically for locating the ends of optical fibres, they may have application in other processes, for example where acceleration measuring devices are constructed using V-shaped grooves with an overhanging beam member which responds to inertial acceleration of the substrate.

A preferred embodiment of the invention will now be described with reference to the accompanying drawings wherein:-

Figure 1 is a view of the substrate carrying an optical coupling aligned by the method described in our copending application 8719557 (F20389); and,

Figures 2 to 8 shown various processing steps in the formation of a substrate by the method according to the present invention.

Referring to Figure 1, a slice of silicon 2 forms a substrate and has formed thereon an array of precisely positioned and dimensioned solder pads 4, formed by photolithographic techniques. The silicon surface surrounding the pads is non-wettable or repellent to solder. In addition, an array of V-shaped grooves 8 are formed which extend to one edge of the substrate dimensioned for receiving therein the ends of an array of optical fibres 10. An optical device 12 formed as a block of material includes optical components comprising ports (waveguides) 14. The lower surface of the block includes an array of solder pads 16 formed in the same manner as solder pads 4 and positioned so as to be in one to one correspondence or registration with pads 4. Solder pads 16 are covered with precisely metered amounts of solder 6 by an evaporation technique involving using an accurately dimensioned mask formed by photolithographic techniques.

In order to assemble the optical coupling of Figure 1, the two arrays of solder pads 4, 16 are brought into coarse alignment and the assembly is raised in temperature until the solder 6 becomes molten. The molten solder will by surface tension effects align the two sets of pads and will form drops of precisely determined dimensions which will establish the height of device 12 above the plane of the substrate to an accuracy typically better than 0.5μm, which is sufficient to establish an accurate optical coupling between fibres 10 and the optical components. On cooling of the solder, the device 12 is rigidly secured to the substrate.

The fibres 10 may be secured into the V-grooves 8 by solder or other suitable adhesive before or after the substrate 2 is attached to

the optical device. Vertical alignment of the fibre cores to the optical waveguides is achieved as a consequence of the original photolithography of the V-grooves which establishes the height of the fibre cores to be the same as that of the optical waveguides 12.

Referring now to Figure 2, there is shown a first step in the processing of a silicon substrate 2. A layer of $S_iO_2$ 30 is grown on the silicon substrate by a conventional oxidation techique, and a thin layer 32 of a suitable metal (for example Cr or Ti/Au) is deposited on layer 30. A layer 34 of negative photoresist is deposited on metal layer 32 and ultraviolet light is shone onto photoresist layer 34 through a photomask 36 in order to define a pattern on photoresist 34 of exposed areas 38. Having performed the irradiation by ultraviolet light and having defined a desired pattern in photoresist 34, the unexposed areas are removed. The layer of metal 32 beneath the unexposed areas is etched subsequently to provide the arrangement shown in Figure 3. As an alternative, a positive photoresist may be used.

In Figure 3, the metal layer 32 is etched down to the $S_iO_2$ layer in regions 40, 42 and all of the photoresist material is dissolved away. The regions 40 define first areas as set forth above (only one of which is shown) and the regions 42 define second areas as set forth above (only one of which is shown). Regions 40 and 42 are accurately positioned relative to one another by reason of the single masking process using a single photomask.

Having thus defined the first and second areas, a layer of negative photoresist 44 is applied over the substrate as indicated in Figure 4. A second photomask is employed to expose the area of the

mask above the second areas 42 to ultraviolet light and leave the area above first areas 40 unexposed so that such mask area can subsequently be removed. This second photomask need not be very accurately defined or positioned since all that is required is a separation of the mask material over the first and second areas 40 and 42. The Photoresist is now developed and the $S_iO_2$ is etched away in areas 40 thus providing a clean substrate surface in these areas. The photoresist 44 may optionally be removed at the end of this step.

Referring now to Figure 5, an etchant material is applied such that V-grooves are etched anisotropically along the <100> plane in the silicon substrate surface in the areas 40. Simultaneously the photoresist material 44 above the second areas 42 is removed, if it has not already been removed (an appropriate etchant is employed), leaving the $S_iO_2$ layer covering the substrate surface exposed in areas 42. A further etching is then carried out as shown in Figure 6 wherein the $S_iO_2$ layers in areas 42 are removed. This is conducted in such a way that there are overhung regions in which the metal ports 48 overhang the etched away sidewalls 50 of the $S_iO_2$ layer therebeneath, effectively widening the second areas 42 at the substrate surface.

It can be seen that the patterning of the substrate surface is therefore essentially a two-step process in which the V-grooves 46 are firstly defined and then the second areas 42 have the substrate surfaces exposed. This is necessary on account of the different etchant conditions required for the etching of the V-grooves and providing the clean substrate surfaces. The layer of metal 32

provides the definition of the second areas and permits these areas to be masked by photoresist material 44 while etching takes place in the first areas. If metal layers 32 were not provided, it would not be possible for the two etching steps to be conducted indepently as is required.

As shown in Figure 7, subsequent to the etching steps a wettable metal is appled by a deposition process comprising Cr/Pt/Au, Ti/Pt/Au or Cu/Cr-Cu/Cu/Au. This permits subsequent soldering of elements and components to the substrate.

The final step is shown in Figure 8 wherein the remaining layer of metal 32 and $SiO_2$ 30 is etched away. This process is greatly aided by the overhanging regions overhanging side walls 50 in the second areas 42 since this permits etchant to attack the whole SiO2 layer, then being a gap between deposited layer 60 and the edges.

## CLAIMS

1. A method of processing a substrate, comprising:-

a) providing a substrate of a material which permits anisotropic etching;

b) forming a layer of a barrier material on the substrate surface and forming a desired pattern in the barrier material by selective removal of the barrier material to provide one or more first areas and one or more second areas, the first and second areas being accurately located relative to one another;

c) forming a masking layer over the or each second area and producing in one or more etching steps, an anisotropically etched V-shaped groove in the or each first area, and selected surface portions in the or each second area; and,

d) etching away the remainder of the barrier material.

2. A method as claimed in claim 1 wherein the substrate comprises silicon.

3. A method as claimed in claim 1 or 2 wherein the layer of barrier material comprises silicon dioxide.

4. A method as claimed in claim 3 wherein the layer of barrier material includes a layer of metal deposited on the silicon dioxide, and only the layer of metal is removed in said selective removal.

5. A method as claimed in any preceding claim wherein said selective removal is carried out by means of a photolithographic process.

6. A method as claimed in any preceding claim wherein the masking layer is formed over the or each second area by a photolithographic process.

7. A method as claimed in claim 1 or 6 wherein the substrate surface is exposed in the or each first area while the masking layer is retained over the or each second area.

8. A method as claimed in claim 7 wherein a V-groove is anisotropically etched in the or each first area.

9. A method as claimed in claim 8 wherein the masking layer is removed simultaneously or subsequent to the formation of the V-grooves.

10. A method as claimed in claim 9 wherein the substrate surface is exposed in the or each second area in an etching step, the walls of the barrier material surrounding the or each second area being overhung.

11. A method as claimed in claim 10 wherein a wettable metallic material is deposited in the or each first area and/or the or each second areas.

12. A method as claimed in claim 11 wherein the remaining barrier material is etched away.

13. A method of processing a substrate substantially as described with reference to Figures 2 to 8 of the accompanying drawings.

14. A method of optical alignment substantially as described with reference to Figure 1 of the accompanying drawings or as claimed in any of the claims of our copending application 8719557 including a substrate processed by a method according to any of claims 1 to 13.